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P3 4 Not so Flappy: Will it Take Off?

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Abstract

This paper investigates the impact of flaps that are used on aircraft during take off, in particular for a Boeing $737-800$. It compares typical take off flap settings, to not using flaps, each setting producing a lift coefficient of 2.1 and 1.4 respectively. Velocities that generate sufficient lift for flight to be possible, for each setting, are found to be ($v_{2.1} = 69.4$ ms^{-1} and $v_{1.4} = 85.0$ ms^{-1}). A net thrust, that accounts for drag on the aircraft, is found for each respective lift coefficient setting ($F_{2.1} = 220$ kN, and $F_{1.4} = 225$ kN) and consequently respective accelerations ($a_{2.1} = 2.78$ ms^{-2}, and $a_{1.4} = 2.85$ ms^{-2}) are calculated. It is found that not using flaps on this aircraft results in a take off distance 404 m longer than when they are used.

Introduction

Aircraft use flaps to change the wing's camber and angle of attack in order to alter the lift produced by the wings at different points of the flight. This paper looks at the take off procedure and how important flaps are for a plane taking off from a standing start with no wind. In particular, how much more runway would a plane need to produce minimum lift to make flight plausible, if it did not use its flaps.

We will consider a commercial plane that has been in operation for a long time, a Boeing $737-800$. This is a good aircraft to model on, due to its fixed wing area at every flap angle. For a plane to take-off, the lift generated by its wings must exceed the weight of the aircraft. Through this paper, we will perform calculations at the point at which these 2 things equal, as the minimum point for flight possibility.

From Figure 1, we can gather lift coefficients, C_l, for a plane's wings for their typical take-off position (blue line peak), as a reference, and the cruise position, meaning flaps are not in use (red line peak). These are taken as $C_{l,flaps} = 2.1$ and $C_{l,noflaps} = 1.4$.

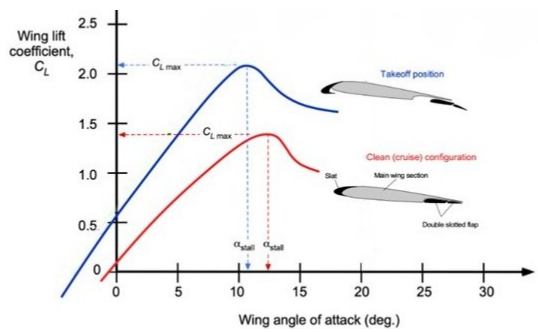

Figure 1: Typical lift coefficients due to flap position for varying parts of the flight [1].

Calculating Minimal Velocity

The lift of the aircraft must exceed the maximum take off weight ($MTOW$, kg) multiplied by g, where the $MTOW$ for a $737-800$ is $79,015$ kg [2], so we will consider lift as: $L = m_{MTOW} \times g$.

The lift equation, rearranged to find the velocity is be given by [3]:

$$v = \sqrt{2L/C_l \rho A}, \tag{1}$$

where v is the aircraft velocity, ρ is the standard air density (1.225 kgm^{-3} [4]) and A is the wing area (125 m^2 [5]).
Following the numbers through this equation for our corresponding coefficients of lift values, gives velocity figures for which the lift is the same as the weight of the aircraft. This yields the result $v_{2.1} = 69.4$ ms^{-1} and $v_{1.4} = 85.0$ ms^{-1}.

Calculating Drag during Take Off

Drag acting on the aircraft is the sum of the drag from air resistance, and the induced drag on the wings due to their lift [6]. The total drag coefficient of the aircraft can be deduced using:

$$C_d = C_{d,0} + C_{d,i}, \tag{2}$$

where C_d is the total drag coefficient on the aircraft, $C_{d,0}$ is the drag at 0 lift (0.0245 [5]), and $C_{d,i}$ is the induced drag.
Induced drag can be calculated using the following equation [6]:

$$C_{d,i} = C_l^2/\pi ARe, \tag{3}$$

where AR is the wing aspect ratio (9.45 [5]) and e is the Oswald factor of the aircraft (0.692 for a 737-800 [5]).
By putting the respective numbers into equations (3), then (2), you find the total drag coefficient for the 2 flap settings: $C_{d,2.1} = 0.239$, and $C_{d,1.4} = 0.120$.
The drag acting on the aircraft can be found using the equation:

$$F_d = \frac{1}{2}\rho v^2 C_d A_{fr}, \tag{4}$$

where F_d is the force of drag and A_{fr} is the frontal reference area, in this case, the face on area of the aircraft.
To find the A_{fr}, we can approximate the fuselage to be a cylinder, and the wings to be cuboids. The maximum diameter of the fuselage is 3.76 m [5]. The average thickness of the wings can be found using the aircraft's wing thickness : chord ratio (10% [5], alongside its mean wing thickness (3.63 m [5]), resulting in an average wing thickness of 0.363 m. This can then be applied to the wing spans of the: main wings (34.32 m [5]), the horizontal stabilisers (14.35 m [5]) and vertical stabiliser, estimated to be around the same span as 1 horizontal stabiliser). Summing these areas gives $A_{fr} = 31.4$ m^2.

Now using equation (4), gives a drag force for the respective lift coefficient settings: $F_{d,2.1} = 22.2$ kN, and $F_{d,1.4} = 16.7$ kN.

Aircraft Acceleration

A Boeing 737−800 is powered by 2 CFM56-7B engines [2], each producing 121 kN of thrust [7]. Considering this and the drag, gives a net thrust for each flap setting: $F_{2.1} = 220$ kN, $F_{1.4} = 225$ kN. Using $F = m_{MTOW}a$, we can find the respective accelerations giving $a_{2.1} = 2.78$ ms^{-2}, and $a_{1.4} = 2.85$ ms^{-2}.

Take Off Distance

To find the distance needed to achieve the aforementioned velocities, we can use the equation:

$$s = (v^2)/2a, \tag{5}$$

where s is the displacement to reach velocity v,. Using the numbers that have been calculated, returns a distance of $s_{2.1} = 866$ m and $s_{1.4} = 1270$ m.

Conclusion and Discussion

A Boeing 737 − 800 would require an extra 404 m of runway to take off, would it not use its flaps. This is a significant distance, empahsising the importance of using physics to improve technology. This paper assumes instantaneous maximum thrust and drag upon the aircraft. Applying an increasing thrust would make the take off distance longer, so in reality, the take off distance would be even larger than stated in the paper. Considering all these variables, shortening the take off distance by 404 m is quite significant and makes taking off in an aircraft significantly easier, simply by using flaps.

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